

Bioconversion of Organic Residues into Single Cell Protein (SCP): Turning Debris into Delicacies

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Abstract

The increasing world deficiency of protein is becoming a major problem for mankind. The conventional sources of protein are scarce and costly and since the early fifties, intense efforts have been made to explore new, alternative and unconventional sources of protein. For this reason, fungi, bacteria and algae have been explored as alternative sources of protein broadly known as single cell protein (SCP). SCP has a number of advantages when used as food or feed; the most important of which is the high protein content (30-80 %) in the cells. Furthermore, SCP also contains fats, carbohydrates, nucleic acids, vitamins and minerals all of which are important dietary components in feeds and food. SCP products are also rich in certain essential amino acids such as lysine and methionine which are usually limiting in most plant and animal foods. Thus, SCP is of high nutritional value for human and/or animal consumption and since SCP production can be done on agricultural and other organic wastes, the utilization of these wastes in SCP production serves two functions; reduction of pollution or environmental conservation and the creation of edible protein. The main aim of this work was to review the use of organic wastes in production of edible protein and to provide highlights on the novelty of SCP.

Keywords : Edible Protein, Organic Wastes, Environmental Conservation, Microbial Biomass

Introduction

Single-cell protein (SCP) refers to sources of protein extracted from cultures of algae, yeasts, fungi or bacteria grown on agricultural wastes and used as a substitute for protein -rich foods in human and animal feeds (Nasseri *et al.*, 2011). SCP has also been defined as microbial cells grown and harvested for animal feed or human food due to its high protein content (Adedayo *et al.*, 2011). The term SCP does not encompass protein derived from the filamentous fungi which are now termed as mycoprotein (Kavanagh, 2005). Since proteins account for the quantitatively important part of the microbial cells, these microorganisms are natural protein concentrates and also contain varying amounts of amino acids (Nasseri *et al.*, 2011). Due to population increase and worldwide protein shortages, use of microbial biomass as food and feed is being considered (Oscar *et al.*, 2010; Nasseri *et al.*, 2011). Protein from microbial biomass has been considered an alternative to conventional expensive protein sources such as fishmeal and soymeal.

Use of microbial protein as food may appear unacceptable but its consumption is certainly innovative to solve global food problems. For many years, man has consumed microbial products such as alcoholic beverages, cheese and yogurt together with the microbial biomass responsible for their production (Tuse, 1984). Microbes that have been used as sources of SCP include yeasts (*Saccharomyces cerevisiae* and *Candida utilis* Torulopsis), bacteria (*Rhodospseudomonas capsulata* and *Cellulomonas*), and algae (*Chlorella* and *Spirulina*) (Becker, 2007; Bhalla *et al.*, 2007).

Chlorella, Cyanobacteria and *Spirulina* are the most commonly cultivated species of algae as SCP (Raja *et al.*, 2008). Yeast is suitable for SCP production because of its superior nutritional quality and general public acceptability but are limited by lower protein content (45-65%) when compared with bacteria (up to 80% ;Oscar *et al.*, 2010). Bacteria grow rapidly on cheap substrates (Oscar *et al.*, 2010) but their use as SCP is limited by their small sizes, high nucleic acid content and the general public thinking that all bacteria are harmful. Algal cells have high protein contents that are comparable to conventional sources of protein (Rasoul -Amini *et al.*, 2009).

Use of Organic Residues as Substrate for Production of SCP (Microbial Farming)

Microorganisms can grow on agricultural wastes and industrial effluents and help in decomposing pollutants (Ashok *et al.*, 2000; Waites *et al.*, 2001). The use of organic residues in production of fungi and other microorganisms as SCP is not only economically viable but also solves the problem of accumulation of organic wastes and protects the environment (Pandey, 2003; Silva *et al.*, 2011). Various hydrocarbon, nitrogenous compounds and agricultural wastes are abundant for production

of SCP (Ashok *et al.*, 2000). Agricultural wastes include wheat bran, molasses, soy bean meals, maize straws and cobs, whey, orange peel residue, bagasse, paper mill waste, rice husks, wheat straw residue, sugar beet pulp, and sweet potato wastes among others (Ashok *et al.*, 2000; Barhim, 2004).

Rapid increase in volume and types of waste agricultural biomass as a result of intensive agriculture is becoming an enormous problem as rotten waste agricultural biomass emits methane and open burning by farmers generate carbon dioxide and other pollutants. Improper management of agricultural waste can contribute to air pollution and climate change (Ashok *et al.*, 2000). This waste however, is of high value with respect to bioconversion of organic refuse which is a sustainable technology that employs organisms that feed on organic matter to convert organic waste into feedstock for livestock and food for man (Ashok *et al.*, 2000). This novel approach to waste management meets organic waste management needs and environmental sustainability in many parts of the world. Production of SCP as animal feed is because the creation of acceptable food from novel sources usually requires animal conversion as a last step in most cases because microbial conversion alone produces biomass that is not acceptable as a food to most consumers in most cases (Nasseri *et al.*, 2011). Cultivation of SCP on organic residues is microbial conversion mediated by man that is oriented at waste management in order to sustain the environment with the production of a useful product in the end (Rolz, 1975).

Choice of Microorganisms for SCP Production

The microorganism of choice should have high growth rate for productivity and good yields. The most important consideration to make is safety and acceptability of the microorganism. Microorganisms involved in SCP production must be safe and acceptable for use in food meaning they should be nonpathogenic and should not produce toxins (Shinohara *et al.*, 2000). There should be ease of recovery of cells from the growth medium and the nutritional composition of the product should be known. Bacteria have faster growth rates than fungi and grow at higher temperatures, thereby reducing fermenter cooling requirements. Bacteria are able to double within 0.5-2 hours, yeast in 1-3 hours and algae within 2-6 hours (Shinohara *et al.*, 2000). In contrast to fungi, which are easily recovered by filtration, bacteria and yeast require the use of sedimentation techniques and centrifugation. Bacteria produce more protein than yeast (50-83% and 30-70% protein content respectively) (Table 1). Organisms should be stable genetically so that the strain with optimal biochemical and physiological characteristics can be maintained through many hundreds of generations (Becker, 2004).

Production Process of SCP

Single Cell Protein develops when microbes ferment waste materials (Vrati, 1983). SCP production technologies were developed to solve the problem of worldwide protein shortage and evolved as bioconversion processes which turned low value products (often wastes) into products with added nutritional and market value (Ugalde & Castrillo, 2007).

The production of SCP is a fermentation process that is done by selected strains of microorganisms which are multiplied on suitable raw materials (Anderson *et al.*, 2005). The cultivation process includes growth of the cell mass followed by separation processes. It begins with microbial screening in which suitable strains are obtained from samples of soil, water, and air and subsequently optimized by selection. The fermentation process requires sterile growth medium in a fermenter, cell separation, collection of cell free supernatant, product purification and effluent treatment (Ferrianti *et al.*, 1983). Prolonging a microbial culture by continuous addition of fresh medium with the simultaneous harvesting of product has been implemented successfully in industrial fermentations destined for biomass production (Cooney, 1986). Fermenters are equipped with aerators to supply oxygen, stirrers, thermostats and pH detectors (Ferrianti *et al.*, 1983; Sinclair & Cantero, 1990).

Many methods are available for concentrating the solutions like filtration, precipitation, centrifugation and the use of semi-permeable membranes (Oura, 1983). After harvesting, the biomass is treated for RNA reduction and dried in steam drums or spray driers to increase their shelf life. Some of the methods for reduction of nucleic acid content in microbial biomass are alkane hydrolysis, chemical extraction, and activation of endogenous nucleases (Sinclair & Cantero, 1990). SCP needs to be dried to 10% moisture or they can be condensed and denatured or acidified to prevent spoilage (Kim & Chung, 2001).

Another production technology involves Solid State Fermentation (SSF) which is the growth of microorganisms on insoluble substrate. The advantage in SSF process is absence of elaborate media preparation and the efficient utilization of substrate to produce commercially viable products (Becker, 2007).

Nutritional Value of SCP

Table 1. Comparison of Nutrient Composition in Algae, Yeasts and Bacteria

Component	% composition of dry weight		
	Algae	Yeast	Bacteria
True Protein	40-60	30-70	50-83
Protein + NAs	45-65	35-50	60-80
Lysine	4.6-7.0	6.5-7.8	4.3-5.8
Methionine	1.4-2.6	1.5-1.8	2.2-3.0
Fats/Lipids	5-10	5-13	8-10
Carbohydrate	9	NA	NA
Nucleic acids	4-6	9.70	15-16
Amino acids	NA	54	65
Fiber	3	NA	NA

Source: Anupama, 2000.

NA-Not Applicable; NAs- Nucleic acids

The production of SCP assumes special significance on account of their nutritional value (Yu *et al.*, 2002). They have high protein content, lipids, vitamins and amino acids (Adedayo *et al.*, 2011) (Table 2). The type of microorganism and medium composition governs the protein and lipid contents of microorganisms (Adedayo *et al.*, 2011). The protein obtained from microorganisms is not only cheap but also provides a balanced nutrition for humans and animals (Rajoka *et al.*, 2006).

Table 2. Comparison of Nutrient Content of some Conventional Food Sources and Microalgae (in % of Dry Weight)

Product	Proteins	CHO	Lipids
<i>Saccharomyces cerevisiae</i>	39	38	1
Meat	43	1	34
Milk	26	38	28
Rice	8	77	2
Soy beans	37	30	20
<i>Anabaena cylindrical</i>	43-56	25-30	4-7
<i>Chlamydomonas reinhardtii</i>	48	17	21
<i>Chlorella vulgaris</i>	51-58	12-17	14-22
<i>Porphyridium cruentum</i>	28-39	40-57	9-14
<i>Scenedesmus obliquus</i>	50-56	10-17	12-14
<i>Spirulina maxima</i>	60-71	13-16	6-7
<i>Synechococcus spp.</i>	63	15	11

Source: Anupama, 2000.

CHO- carbohydrates

The mean crude protein in dry matter of algae and yeasts on conventional substrates lies between 40-70 % and 50-80 % for bacteria (Table 1). Bacterial protein content is the highest (50-80 % of total cell contents) (Anupama, 2000; Kurbanoglu, 2011) while microalgae have the highest lipid content. Bacterial products have the highest content of methionine (2.2-3.0%) but generally low lysine (4.3-5.8%) while algal cells have the highest lysine content (4.6-7.0%) (Anupama, 2000; Kurbanoglu, 2011). SCP from yeast has up to about 30-70% protein (Table 1) and has high protein – carbohydrate ratio (38:39) (Table 2). It is rich in lysine (6.5-7.8% but poor in methionine (1.5-1.8%) (Table 1) (Anupama, 2000). It also has good balance of amino acids (54%) and is rich in B –complex vitamins and more suitable as poultry feed (Anupama, 2000; Adedayo *et al.*, 2011). Some yeasts have probiotic properties when used in aquaculture,

such as *Saccharomyces cerevisiae* (Oliva-Teles & Goncalves, 2001) and *Debaryomyces hansenii* (Tovar *et al.*, 2002) and can boost larval survival of fish (Campa-Cordova *et al.*, 2002, Burgents *et al.*, 2004). However, many of these yeast supplements are deficient in sulfated amino acids like methionine (Oliva - Teles & Goncalves, 2001) which restricts their extensive use as the sole protein source.

Algae can provide many vitamins including: A, B1, B2, B6, niacin and C, and are rich in iodine, potassium, iron, magnesium and calcium (Simoons, 1991). Commercially cultivated microalgae such as Cyanobacteria are marketed as nutritional supplements for example *Spirulina* and *Chlorella* (Morton, 2000). Lipids in microalgae are especially important because of the high concentration of omega -3 fatty acids which are essential polyunsaturated fatty acids and must be obtained from dietary sources (Morton, 2000). The conventional sources of this essential fatty acid include fish, soy beans and eggs which may present allergic reactions in some users or may be out of reach to many (Morton, 2000).

Advantages of SCP

Large-scale production of microbial biomass has many advantages over the traditional methods for producing proteins for food or feed. Microorganisms have a high rate of multiplication (algae: 2-6 hours, yeast: 1-3 hours, bacteria: 0.5-2 hours) thus mass production and high productivity is amenable (Adedayo *et al.*, 2011). They can be easily genetically modified for improved protein composition. There is high efficiency of substrate conversion and algae grown in ponds produce 20 tons (dry weight) of protein per acre/year which is 10-15 times higher than in soybeans and 20-50 times higher than in corn (Ashok *et al.*, 2011). They can utilize a broad spectrum of raw materials as carbon sources, which include those from waste products and thus they help in the removal of pollutants from the environment (Adedayo *et al.*, 2011; Ashok *et al.*, 2011). Besides the nutritional values of SCP, it also has the benefits of the possibility of its production through -out the year since it is independent of seasonal and climatic conditions (Ndihi, 2010). Since microbial biomass production occurs in continuous cultures (Ndihi, 2010; Adedayo *et al.*, 2011), land requirements are low and are ecologically beneficial (Adedayo *et al.*, 2011). SCP for example requires no arable land and can be grown even in deserts (Adedayo *et al.*, 2011). Algal cultures can be done in places that are normally unused and so there is no competition for agricultural land (Adedayo *et al.*, 2011).

Limitations of SCP

Despite the novel features of SCP, there are several factors that contribute to its limited use globally. High nucleic acid content (6-10%) is the most important factors limiting nutritional value of SCP for animal or human consumption (Adedayo *et al.*, 2011). The concentration of nucleic acid in SCP is higher than in other conventional protein and is characteristic of all fast growing organisms (Adedayo *et al.*, 2011). Consumption of food with high nucleic acid concentration leads to production of uric acid in the blood causing health disorders such as gout and kidney stones (Nasseri *et al.*, 2011). Microbial biomass may also have unacceptable color and flavors (Adedayo *et al.*, 2011).

Sometimes the microbial biomass when eaten may lead to indigestion or allergic reactions in humans (Adedayo *et al.*, 2011). Skin and gastrointestinal reactions resulting into nausea and vomiting have been reported from consumption of foreign protein (Adedayo *et al.*, 2011). SCP from algae may not be suitable for human consumption because they are rich in chlorophyll and have cellulosic cell walls (about 10% of dry matter) that is not digestible for humans and other non -ruminants (Rasoul-Amini *et al.*, 2009). Some contaminants during production process of algal SCP can produce mycotoxins and other cells have low growth rates and low protein content (45-65%) and lower methionine content than in bacteria. Algal SCP also concentrates heavy metals (Becker, 2007; Richmond, 2004). However, some processes have been employed to treat algal biomass to disrupt the cell wall before consumption and these include boiling, high temperature drying, sun drying, and chemical autolysis (Becker, 2004). Bacterial cells have small sizes and low density which makes harvesting from fermented media difficult and costly. Bacterial cells also have high nucleic acid content and require additional processing to reduce the nucleic acid content (Adedayo *et al.*, 2011). The greatest limitation of bacteria as SCP is the general public view that all bacteria are harmful and cause disease. There is lack of familiarity and acceptability for bacteria as food hence the need for public education to dispel this misconception and make the public accept bacterial protein (Nasseri *et al.*, 2011). All these detrimental factors affect the acceptability of SCP as global food.

Future Prospects of SCP Production

Research on SCP is stimulated by concern over eventual food crisis that will occur if the world's population is not controlled (Adedayo *et al.*, 2011). The use of microbes for production of proteins gives

many advantages over the conventional sources. Microbes have shorter generation time, utilize many substrates, and have no requirements for arable land or any particular season to grow so have the possibility of continuous production in any part of the world.

However, many people are still reluctant about microbial food and much education is needed before the full advantage of the novel nutritional value of such cheap and readily available food source can be used. Maximum utilization of agro-industrial wastes will inevitably result in better environmental management and improve the quality of life from added income.

The future of SCP is heavily dependent on reducing production costs, improving downstream processing and the producer organisms by means of recombinant DNA technologies. SCP is gaining research interest among scientists in universities and industries and now SCP is being used in some parts of the world for animal and human consumption (Nasseri *et al.*, 2011). The use of SCP as food ingredient is still in its early stages of development and attempts to improve the acceptability of SCP products should be intensified. Further research and development will ensure usage of microbial biomass as SCP or as diet supplements.

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